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Technical Report EE-70

MEASUREMENTS OF ELECTROMAGNETIC ATMOSPHERIC NOISE IN THE 3-50 cps REGION

by

James F. White*

February 1962

(Supplement to Technical Report EE-69)

*E. E. Department
University of New Mexico
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This work was performed under
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Introduction

A research of the literature undertaken in September, 1960 indicated that while considerable theoretical and experimental work had been done in atmospheric noise in the VLF region, noise data in the ELF region was rather limited. Very little effort has been specifically directed to securing evidence of the earth-ionosphere cavity resonant frequencies which has been predicted by Schumann. As a consequence this investigation was initiated to secure atmospheric noise data in the 3 to 50 cps region of the spectrum and in particular to secure evidence of the Schumann mode frequencies. While the experiment reported in this paper was in progress evidence of the Schumann frequencies was reported by several investigators--Balser and Wagner according to Raemer [1961], Fitchen et al. [1961], and Maple [1961]. The results of these investigators and those presented here are comparable.

Experimental Procedure

In order to avoid power line and other forms of man-made interference, portable equipment was employed to collect the noise data at a remote location on the Isleta Indian Reservation (34° 54' N, 106° 34' W True). A block diagram of the data-collecting system is shown in Figure 1. The output of the 4.4 meter vertical antenna is fed to the amplifier through a pre-amplifier which serves as an impedance matching device. A 2,000 cps low pass filter is incorporated in the amplifier to eliminate high frequency signals.

The output of the amplifier is frequency translated by a switching technique to within the frequency response region of a tape recorder and recorded on one track of a duo-channel magnetic tape. Simultaneously the basic oscillator (1,000 cps) which drives the switch is recorded on the other track of the magnetic tape. This signal is used for synchronization during the playback mode.

In the playback mode, shown in Figure 2, the synchronizing signal drives the switch to re-translate the data to its original position in the spectrum. Variations in the tape speed during record and playback cause the same percentage frequency variation in the data and synchronizing signal. Thus the data is demodulated during playback in such a manner that both the data carrier signal and synchronizing signal are always the same frequency and in phase. Technical Report EE-69 (University of New Mexico) describes this modulation system in detail.

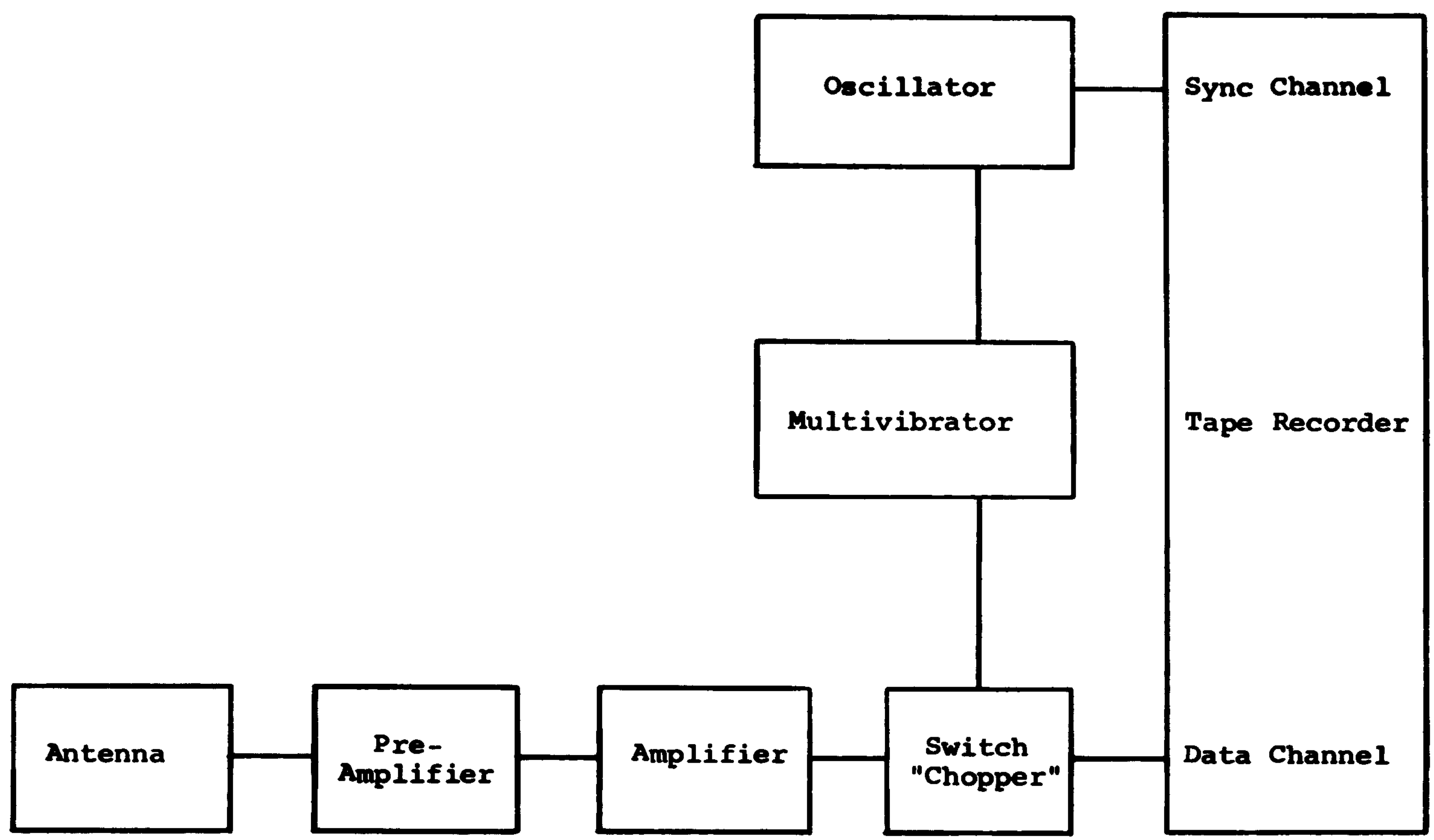

Figure 1. Block diagram of data-collecting system

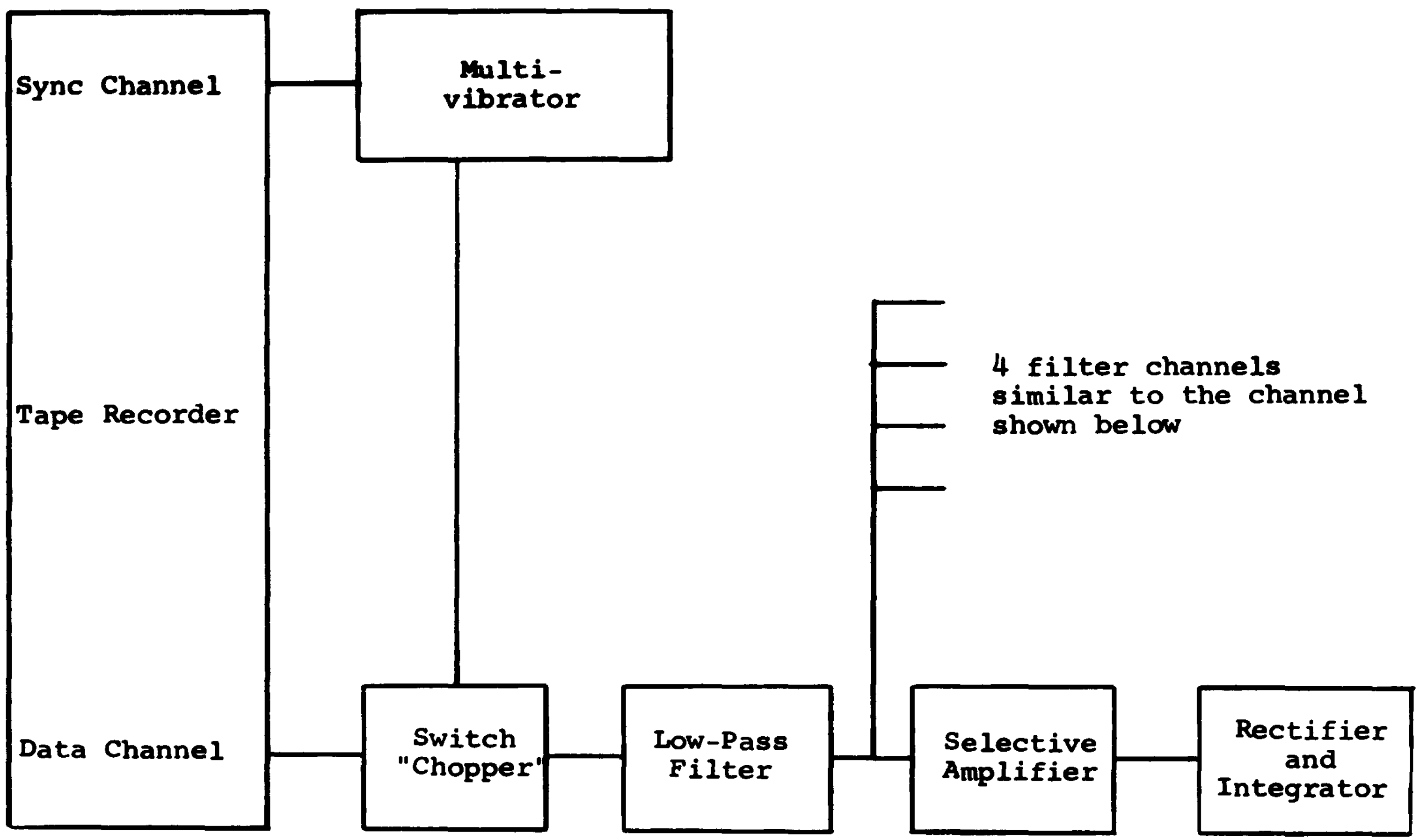

Figure 2. Block diagram of data-processing system

After demodulation, the data from the switch is fed through a low-pass filter to remove all frequencies above 50 cps. The output of the filter is connected to five filter channels which are in parallel. Each channel contains a selective amplifier (White Instrument Laboratories, Model 212) with a twin-T filter (White Instrument Laboratories, Type 542). The output of each selective amplifier is rectified and then integrated by one channel of a five-channel analog computer (Donner, Model 3400). The middle 20 minutes of each 32-minute tape is processed twice using five different filters for each run. The ten frequencies involved in this filtering process are shown on the graphs of the data.

In the complete recording and recovery process, the noise data is subjected to two variations with known limits. These variations are due to the frequency response of the receiver and changes in the receiver gain. The frequency response is within 3 db from 3 to 2000 cps. Variation in gain is measured by a test circuit incorporated in the receiver and maintained within 1.2 db. Under these limitations, test tapes at frequencies in the 3 to 50 cps region provide a means of determining the gain in the recording and in the processing system. The gain in each filter channel is considered separately during data processing. The combined computer drift and inter-channel interference is less than 2.6%. Each channel has a .025 per unit bandwidth. The output of the computer is put in terms of the mean peak value at the rectifier input. Since the system gain and antenna effective height are known the rectifier input is determined and plotted as the mean peak value of field strength.

Theory

The earth-ionosphere cavity resonant or mode frequencies were determined by Schumann [1952] as

$$n(n+1) = \frac{2\pi r}{c} f\left(1 + \frac{\delta}{r}\right) \qquad (1)$$

where r - radius of the earth (≈ 6360 km),

c - velocity of light (3×10^8 m/sec),

and δ - height of the ionosphere.

This relation was developed under the condition that the attenuation coefficient, α, was equal to zero, i.e., perfectly conducting boundaries. With $\delta = 100$ km, equation (1) becomes

$$f_n = \frac{7.5}{1.02} \sqrt{n(n+1)} \qquad (2)$$

which gives

$$\begin{aligned} f_1 &= 10.6 \text{ cps}, \\ f_2 &= 18.3 \text{ cps}, \\ f_3 &= 25.9 \text{ cps}, \\ f_4 &= 33.5 \text{ cps, etc.} \end{aligned} \qquad (3)$$

In considering the conductivity of the ionosphere, Wait [1960] showed that the mode frequencies are modified according to the relation

$$f_n' = f_n - \frac{\alpha \sqrt{f_n}}{4\sqrt{\pi}} \qquad (4)$$

where f_n are the Schumann mode frequencies. The attenuation coefficient, α, in equation (4) is given by

$$\alpha = \frac{1}{h\sqrt{\mu_o \sigma_i}} \qquad (5)$$

where $\mu_o = 4 \times 10^{-7}$ h/m,

h - height of the ionosphere in km,

and σ_i - conductivity of the ionosphere in mhos/m.

Since α is a function of h and σ_i, there are many combinations of h and σ_i that could give a particular α. Curves of equation (5) are shown in Figure 3. These curves are normalized to α = .893 which value occurs when h = 100 km and $\sigma_i = 10^{-4}$ mhos/m.

With α = 0.893 and h = 100 km, the Schumann frequencies, f_n, given in (3) are then modified as in (4) to give

$$f_n' = f_n - \frac{.893\sqrt{f_n}}{4\sqrt{\pi}}$$

$$f_n' = f_n - .126\sqrt{f_n} \, . \qquad (6)$$

A plot of f_n' versus f_n for various multiples of α_o (normalized to α = 0.893) is shown in Figure 4. Considering h and σ_i to be independent of frequency, at least at the lower mode frequencies [Raemer 1961], it appears that evidence of a particular mode frequency in experimental data would also give sufficient information to resolve other, perhaps less evident, mode frequencies in the same data. Thus α determined at a particular frequency in a set of data should be the same at the other mode frequencies in that data.

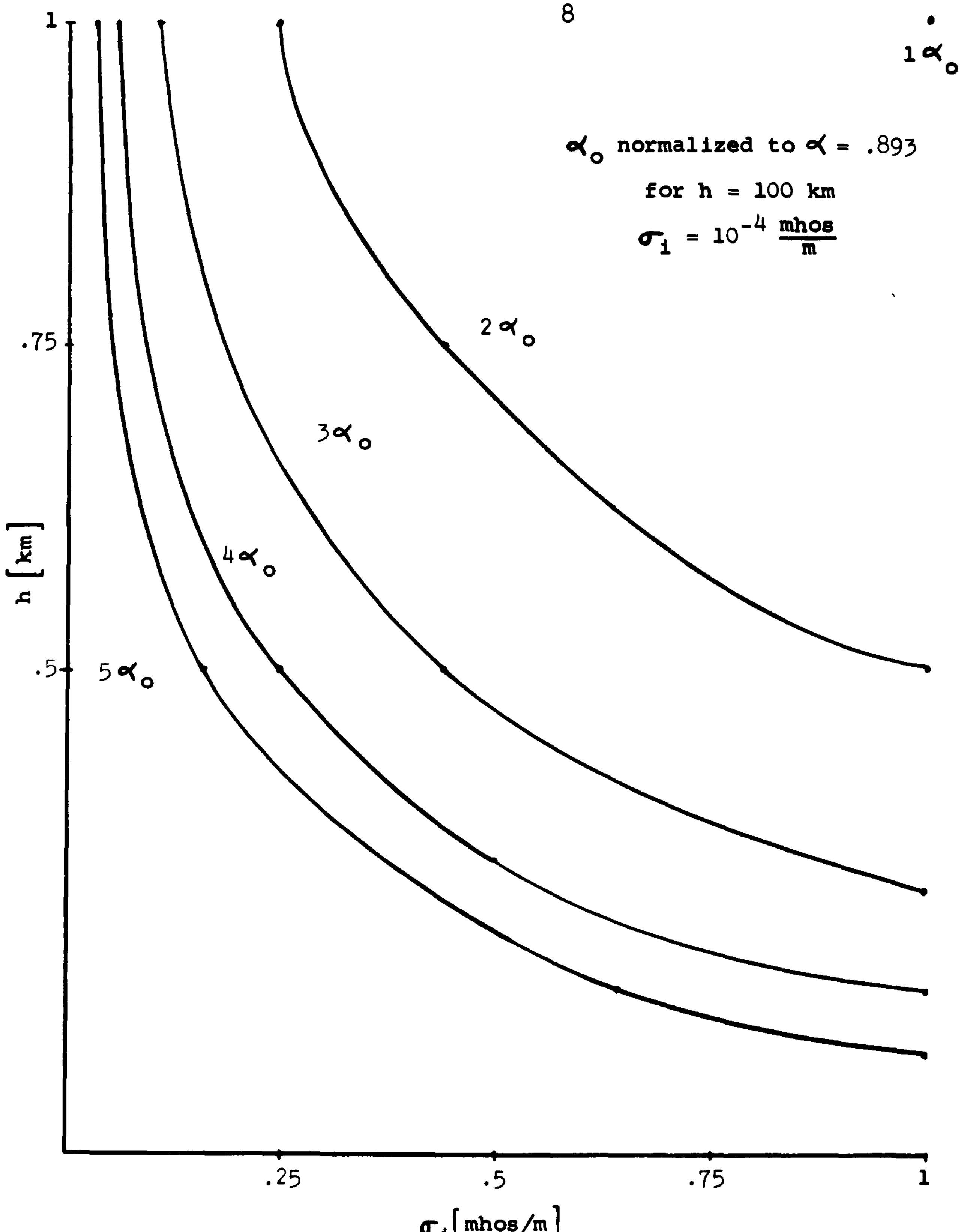

Figure 4. Variation in ionosphere height and conductivity for values of attenuation coefficient

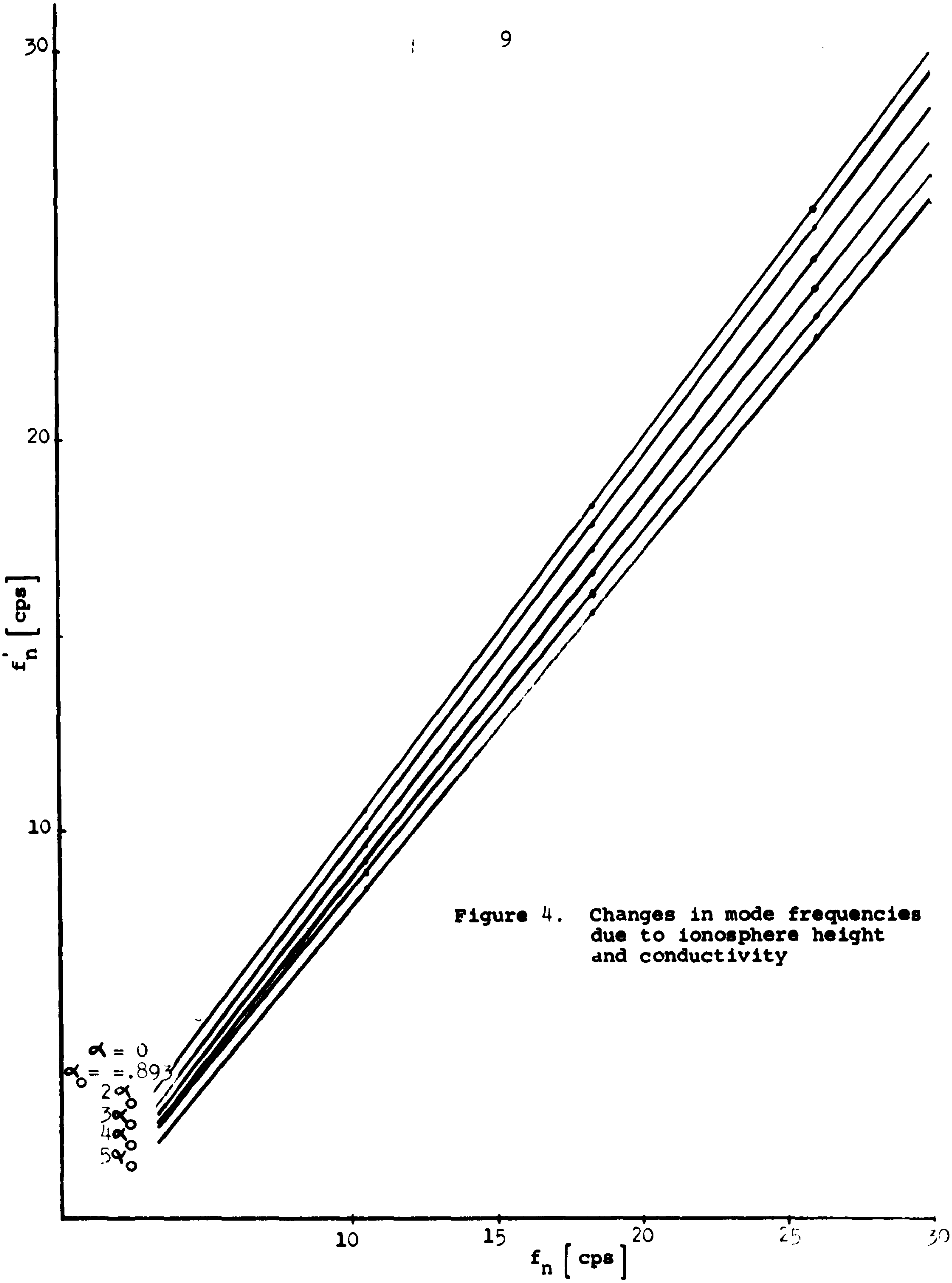

Figure 4. Changes in mode frequencies due to ionosphere height and conductivity

Observations

The data was recorded during hourly period from 0900 to 1300 hours MST (1600-2000 GMT) daily for the five week period, July 31 to September 8, 1961. The observations were averaged to obtain an average field strength for each particular hour during the complete five week period. In addition, the difference between the maximum and minimum observations at each frequency for each hour were determined on a weekly basis and then averaged for the period.

The average field strengths for the period observed during 09-10, 10-11, 11-12, and 12-1300 are presented in Figures 5, 6, 7, and 8, respectively. A composite presentation for comparison purposes is given in Figure 9. A few features of these figures are immediately apparent. The magnitude of the noise in the 5 to 10 cps region is approximately twice that in any other part of the observed spectrum. There is a definite peaking at 15.5 cps. The magnitude of the noise in the 28 cps region is approximately half that in the 5 to 10 cps region but greater than other parts of the spectrum.

A study of these figures indicates that the pattern is very similar from hour to hour. In addition, the magnitude of this pattern increases with time during the 08-1300 daily observation period. The peaking and the symmetry at 15.5 cps is very consistent. This would seem to indicate that in this region the mode frequency is very close to 15.5 cps.

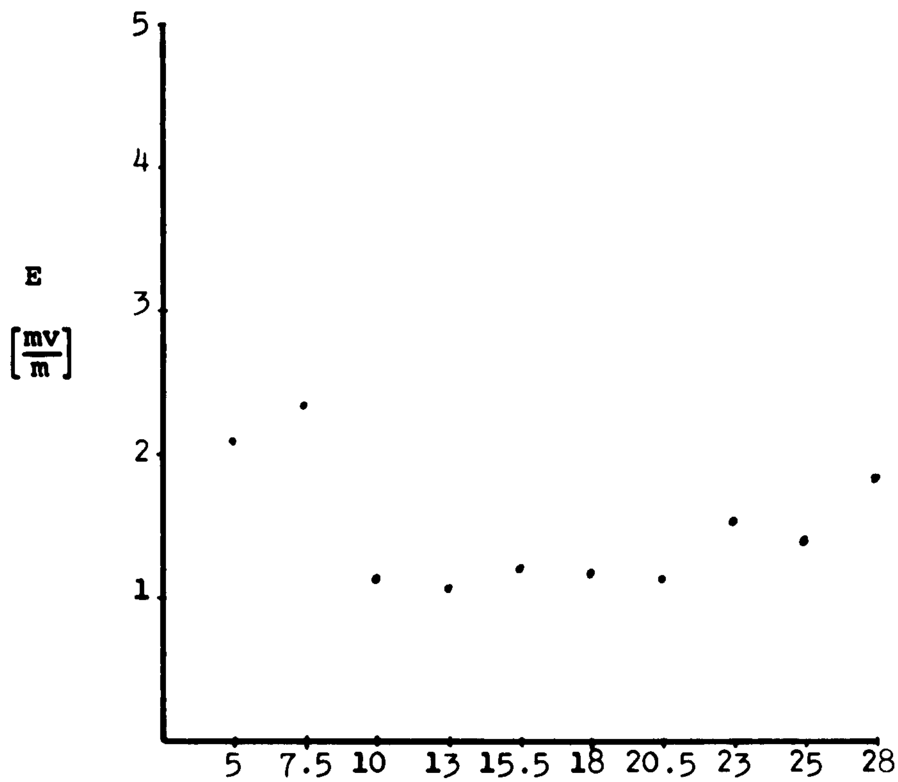

Figure 5. **Average value of observed field strength during 0900-1000 (MST) for period 31 July to 8 September 1961**

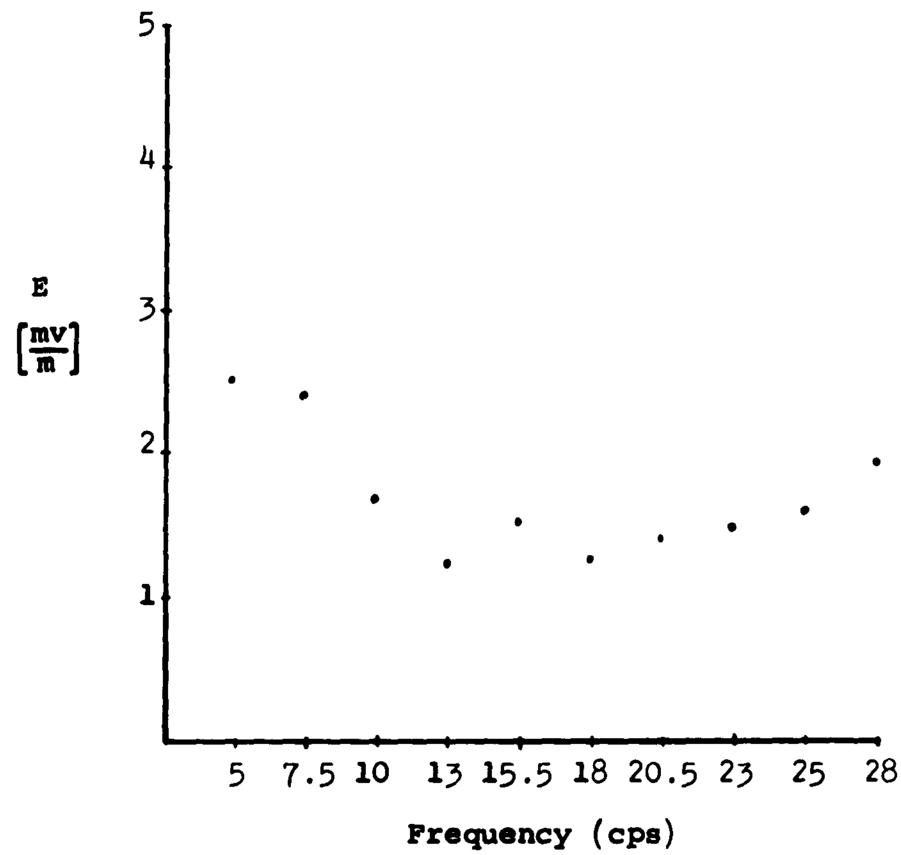

Figure 6. Average value of observed field strength during 1000-1100 (MST) for period 31 July to 8 September 1961

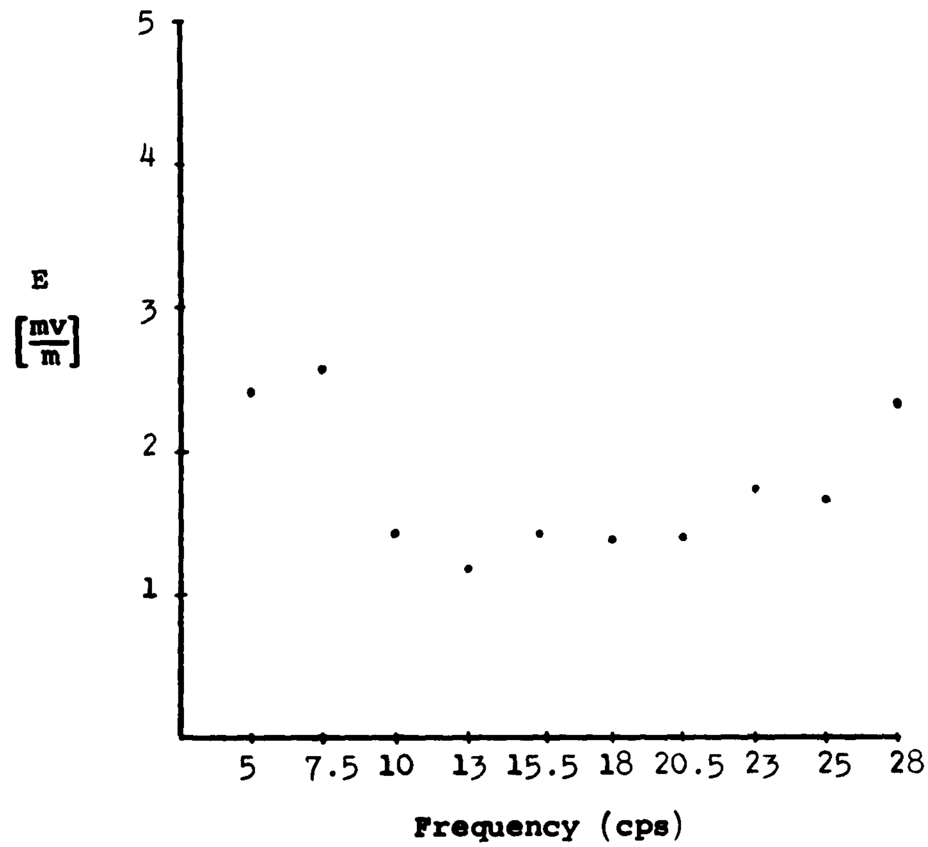

Figure 7. Average value of observed field strength during 1100-1200 (MST) for period 31 July to 8 September 1961

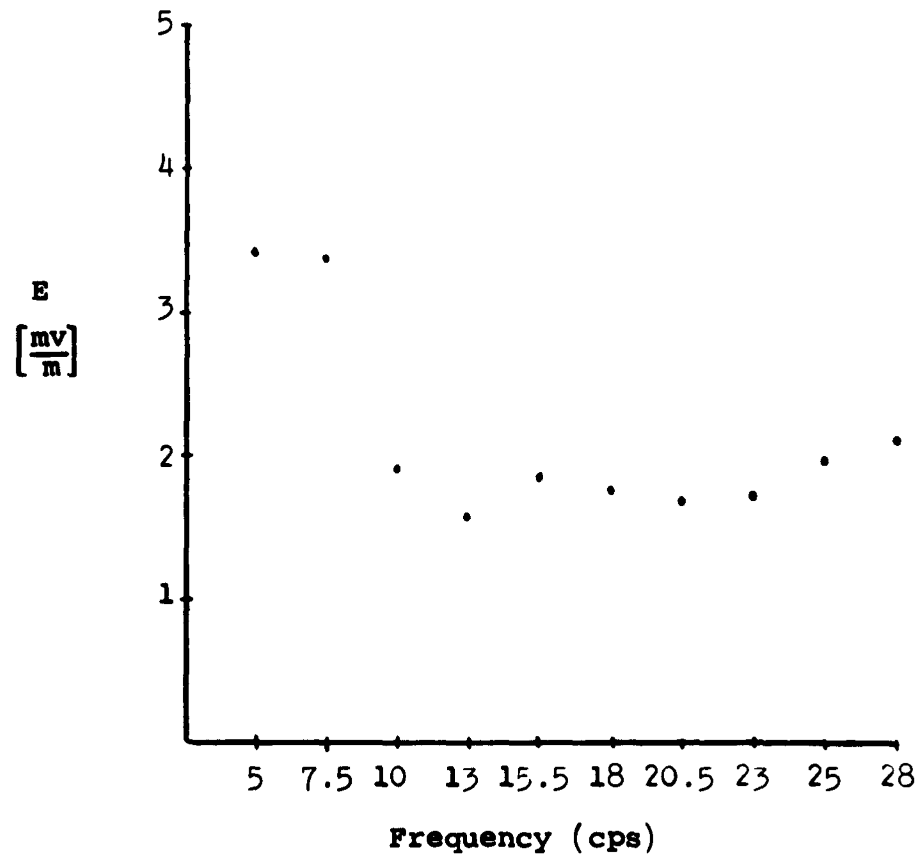

Figure 8. Average value of observed field strength during 1200-1300 (MST) for period 31 July to 8 September 1961

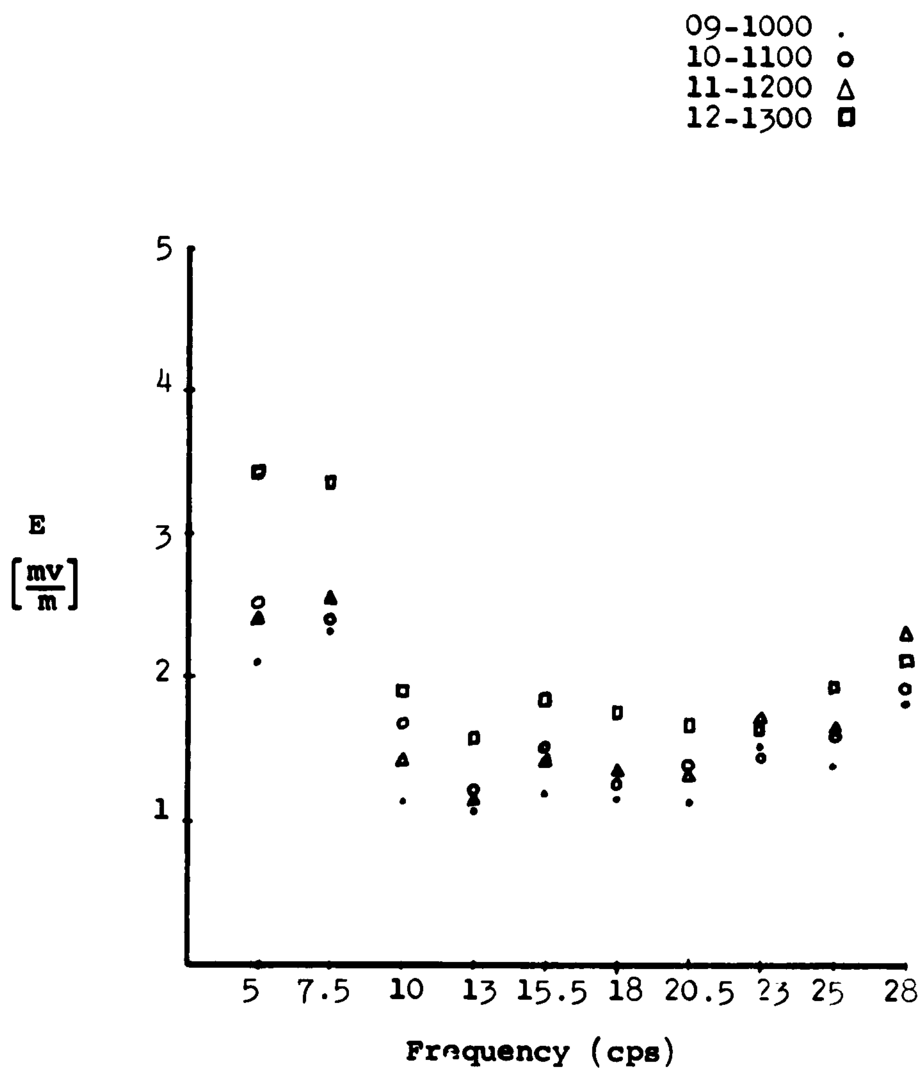

Figure 9. Average values of field strength during designated hours (MST) for period 31 July to 8 September 1961

While the greater magnitude at 23 cps is apparent at some hours, it is not consistently evident. This fact is due possibly to the influence of the generally increasing magnitude in the 23 to 28 cps region.

A study of the noise spectra reveals that the magnitude of the noise rises quite sharply in the 13 to 10 cps region. The consistency of this shape seems to indicate the existence of a peaking in the 7.5 to 10 cps region. Filter spacing used in the analysis was obviously too coarse for good resolution in this area. In order to determine the existence of a mode frequency in this region, additional filter processing could be performed. However, in view of the pronounced peak at 15.5 cps and the consistency of α for a set of data (shown previously), it appears reasonable to resolve the 7.5 to 10 cps region with the aid of equation (6).

Considering the peak at 15.5 cps, equation (6) becomes

$$.126\sqrt{f_n} = 2.8 = \frac{\alpha}{7.08}\sqrt{18.3}\,,$$

and $\qquad \alpha = 4.64$

or $\qquad 5.2\,\alpha_o$ (normalized to $\alpha = .893$).

Now applying $5.2\,\alpha_o$ to equation (6) for 10.6 cps (f_1) gives

$$f_1' = 10.6 - (5.2)(0.126)\sqrt{10.6}$$

$$f_1' = 10.6 - 2.132 = 8.47 \text{ cps},$$

for 25.9 cps (f_3) gives

$$f_3' = 25.9 - 3.328 = 22.57 \text{ cps},$$

and for 33.5 cps (f_4) gives

$$f_4' = 33.5 - 3.7856 = 29.7 \text{ cps}.$$

Thus f_3' agrees quite well with the data. The frequency, f_4', accounts for the ever-present peaking as the frequency increases to 28 cps.

The efficacy of the above method in determining the mode frequencies can be demonstrated using the experimental data obtained in this region of the spectrum by Balser and Wagner [1961]. Their experimental results indicate that $f_1' = 8.2$ cps. Using equation (6), $\alpha = 5.23$ or $5.86\alpha_o$. The results of considering in turn $f_2' = 14.1$ cps, $f_3' = 20.3$ cps, and $f_4' = 26.3$ cps show that they all involve $5.86\alpha_o$.

The results of observations during the evening hours (September 11 to 15, 1961) are presented in Figure 10. The intent here was to determine if variations in ionosphere height or conductivity would be manifested by a shift in the mode frequencies. For some hours there is a peaking at 18 cps. Perusal of the data indicates, however, that the averages are peaked at 15.5 cps and that no shift is evident. The 23-2400 hour readings which give the appearance of 18 cps peaking are somewhat erratic and questionable. The limited amount of data precludes noting any significant shift of mode frequencies during the night hours.

The average of the difference between maximum and minimum observed field strengths for the recording period at the various hours 09-1300 are shown in Figures 11, 12, 13, and 14. The

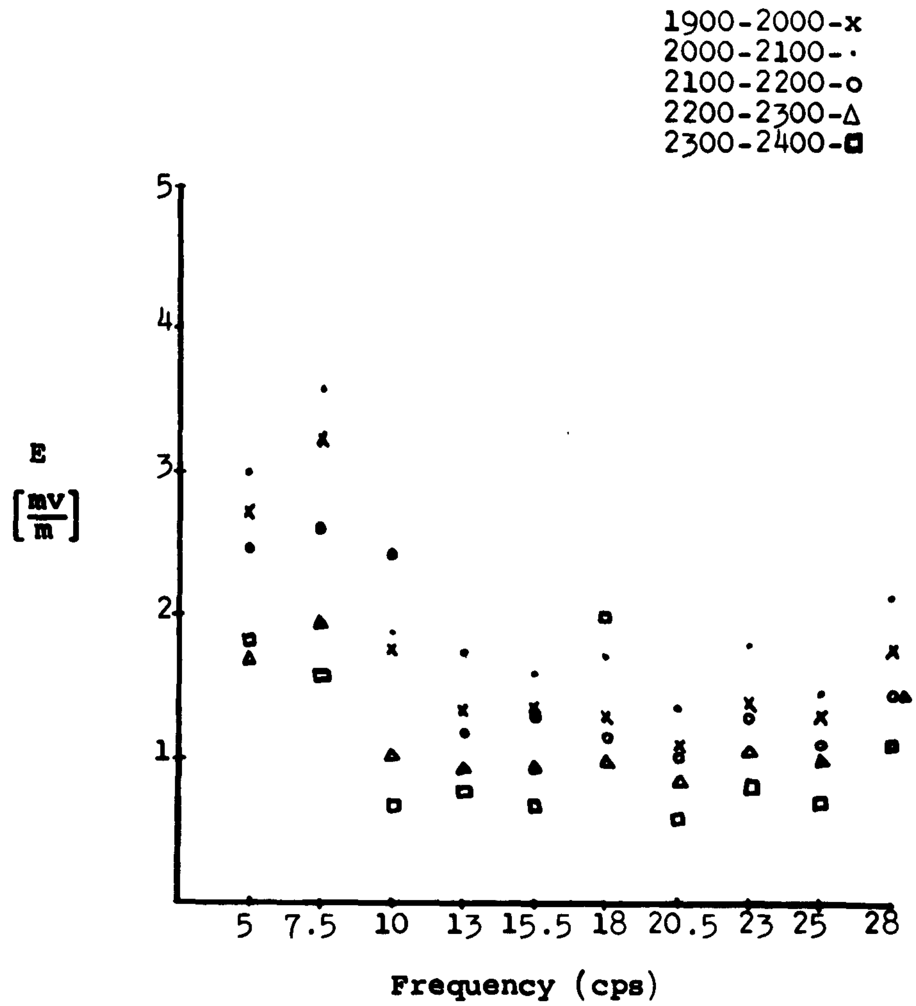

Figure 10. Average values of field strength during designated hours for period 11-15 Sept. 1961

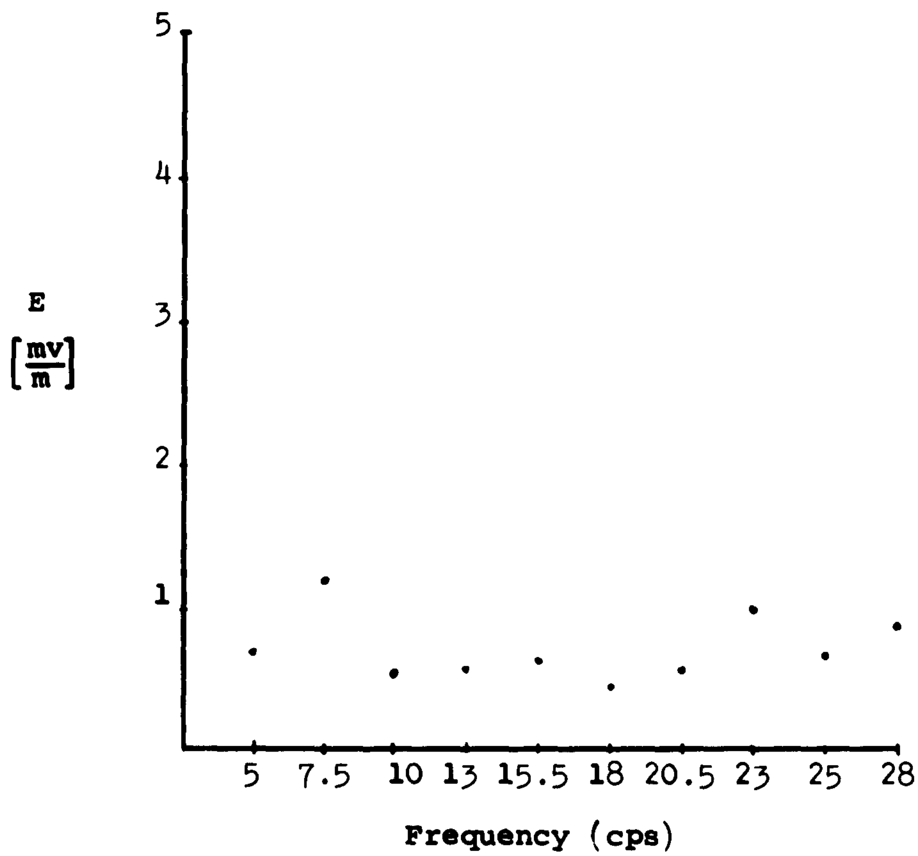

Figure 11. **Average difference of field strength during 0900-1000 (MST) for period 31 July to 8 September 1961**

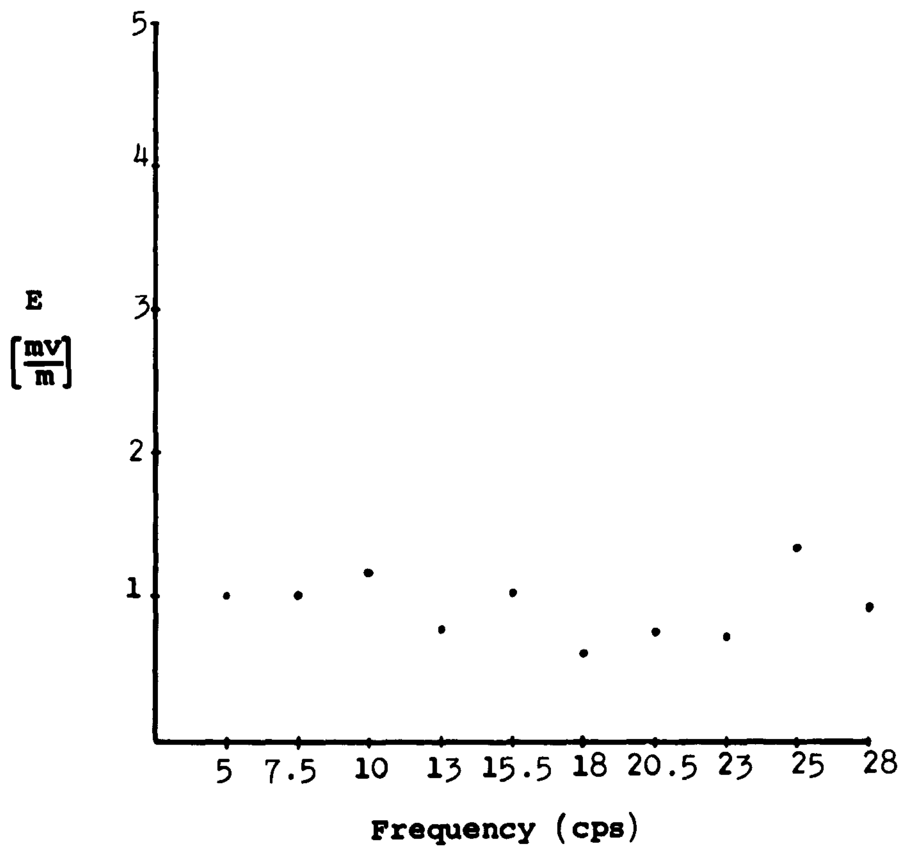

Figure 12. **Average difference of field strength during 1000-1100 (MST) for period 31 July to 8 September 1961**

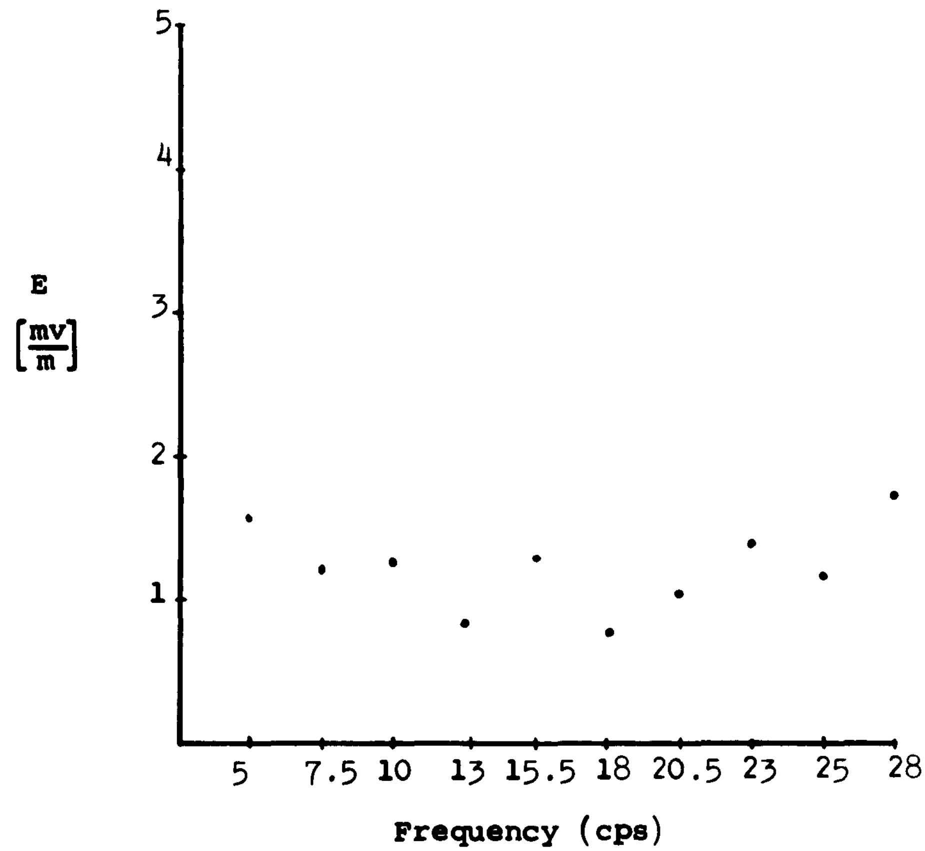

Figure 13. **Average difference in field strength during 1100-1200 (MST) for period 31 July to 8 September 1961**

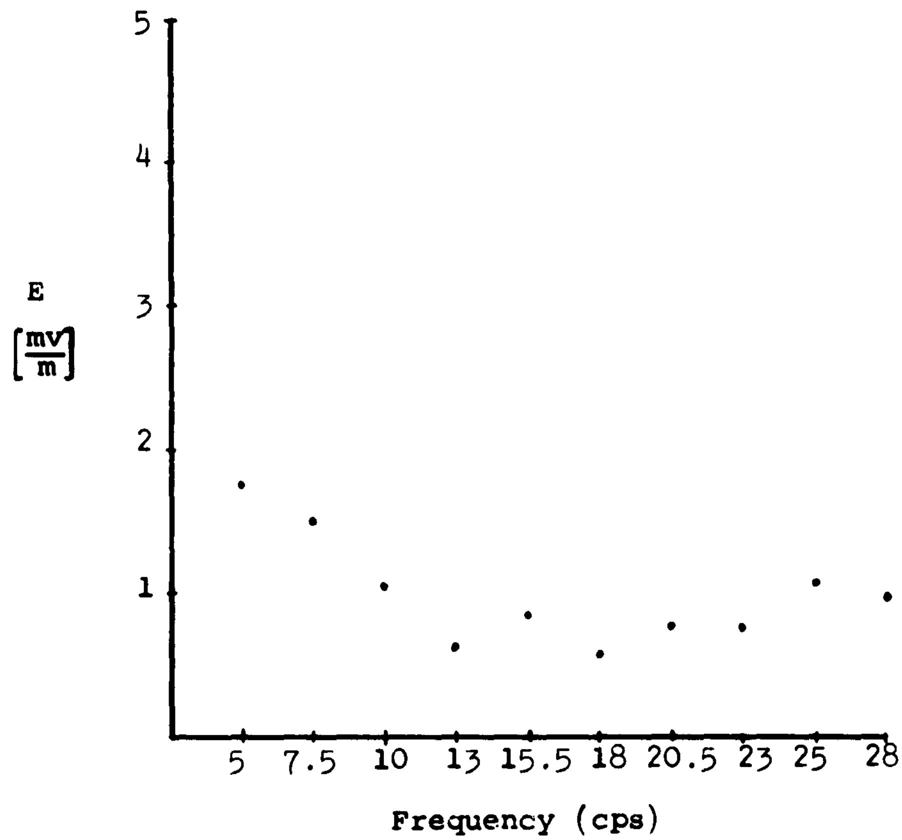

Figure 14. **Average difference in field strength during 1200-1300 (MST) for period 31 July to 8 September 1961**

difference between maximum and minimum field strengths recorded in an hourly period for a week are averaged. The average difference over the five week recording period is then determined from the weekly average. The average difference for the period at the different hours in shown for comparison purposes in Figure 15. The maximum average difference occurs at the same mode frequencies as the average values shown in Figure 9. This seems to indicate that the activity at the mode frequencies is not only greater on the average but also more varied.

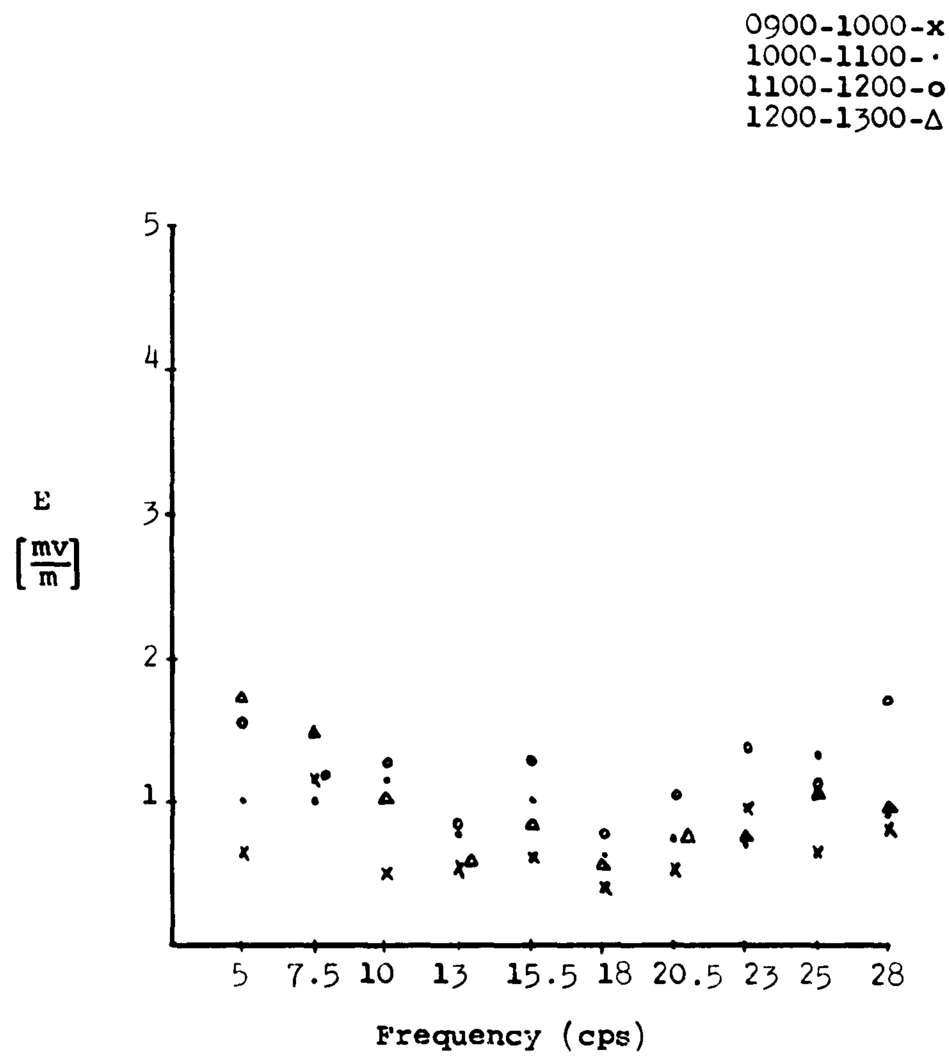

Figure 15. Average difference of field strength during 0900-1300 (MST) for period 31 July to 8 September 1961

Conclusions

Evidence of earth-ionosphere cavity mode frequencies has been experimentally obtained. The results indicate that the lower mode frequencies are

$$f_1 \approx 8.5 \text{ cps}$$

$$f_2 \approx 15.5 \text{ cps}$$

and $f_3 \approx 22.6$ cps.

The comparatively small amount of data secured during the evening hours precludes noting any change in the mode frequencies due to changes in ionosphere height or conductivity.

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